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proves with VA content, and the most efficient modifiers are in the range of 40–50 wt % VA.

Advantages include good heat and light stability, improved processing, weathering similar to acrylics, chemical resistance, good low-temperature performance, and lower melt viscosity. These modifiers are used for opaque weatherable products.

#### Other plastics uses

Recent activity has centered on impact modifiers (usually elastomers) in plastics other than PVC:

- Polybutylene to enhance processability, toughness, and heat sealability of polypropylene film;
- Olefinic thermoplastic elastomers for tear strength in polypropylene film and for crystalline engineering thermoplastics;
- Rubbers and thermoplastic elastomers (such as ethylene-propylene copolymers) for toughness and stress-crack resistance of polyolefins;
- Hydroxyl-terminated polyethers for increased impact resistance of polystyrene;
- Styrene butadiene multiblocks to increase impact in HIPS;
- ABS to modify polycarbonate, polyurethane, thermoplastic polyester, epoxy, and polysulfone;
- Elastomers for impact resistance in unsaturated polyester prepolymers; and
- Diene styrene thermoplastic elastomers in polystyrene, polypropylene, and HDPE (increased impact and tear strength of blown HDPE film).

#### Low-Profile Additives

When unsaturated polyester resins are copolymerized with crosslinking monomers, the high shrinkage that occurs during curing causes a compound to pull away from the surface of molds and fibrous reinforcements. This nonuniform shrinkage reduces the accuracy of mold-surface reproduction, leaves fiber patterns and sink marks on the part surface, creates stresses that induce warpage and internal cracking, and makes close molding tolerances difficult to achieve.

Thermoplastic and elastomeric polymer low-profile agents (LPAs) have been developed to compensate for the shrinkage and eliminate the problems it causes.

#### Elastomeric LPAs

Rubber or elastomeric materials, such as butadiene-styrene and styrene-butadiene-styrene, make effective low-shrink and low-profile modifiers for painted and internally pigmented SMC and BMC.

Concentrations of 12.5% can produce SMC and BMC low-shrink compounds when surface waviness and sink are not crit-

ical. For maximum surface properties, 15% gives good molded appearance even in large, relatively flat, thin panels.

Because the LPAs contribute to good flow, large parts can be compression molded with lower-tonnage presses. The rubber-modified composites are said to have a good balance of properties, with slightly lower modulus and lower hardness compared to composites with thermoplastic additives. The rubber, however, provides increased tensile elongation and impact strength and decreased shrinkages.

A family of modified polyurethane LPAs was designed to be used in existing SMC and BMC formulations in the same manner as conventional low-profile additives. Polymer backbones can be changed to achieve specific end effects, and lower viscosities allow higher filler loading and easier processing, which is especially significant for increasing loadings of ATH for flame-retarded applications.

#### Thermoplastic LPAs

During crosslinking (curing) of unsaturated polyester, a thermoplastic LPA becomes incompatible with the matrix. The thermal expansion of the thermoplastic phase, under the heat and pressure of the molding operation, offsets the shrinkage of the thermosetting matrix. This reduction or elimination of shrinkage eliminates warpage, internal stress, and surface fiber patterns, permitting close-molding tolerances and very smooth part surfaces.

There are five types of thermoplastics commercially employed as LPAs: polyvinyl acetates (PVAs), polymethylmethacrylates (PMMA's), polycaprolactones, polystyrenes, and polyethylene. They are effective at concentrations of 3–5 wt % in the total formulation and are generally sold as 30–40 wt % solutions in styrene monomer, composing about 10% of the total formulation. A new family of LPAs, based on calcium carbonate encapsulated in a typical thermoplastic LPA, comes in the form of a fine bead or a free-flowing powder free of styrene monomer.

Proper pairing of LPA and unsaturated polyester resins is critical to performance. Molecular weights and other properties of each partner must be carefully controlled. The LPA should not interfere with the free-radical cure of the unsaturated polyester (which would increase cure time) or inhibit the complex chemical thickening reaction of SMC.

LPAs perform differently, depending on the molecular characteristics of their polymer, and have been divided into two general application categories: painted parts and internally pigmented (molded-in color) parts.

• **Painted parts.** Transportation is the biggest consumer of painted parts. The primary re-

quirements are for excellent shrinkage control, surface appearance, and paintability. The LPA often used is a polyvinyl acetate. Polymethylmethacrylates, the first LPAs used for painted parts, provide acceptable results in some situations but not in newer applications.

• **Molded-in color** can be considerably more efficient, but internal pigmentation problems in this system. The complete profile mechanism of the system remains chemically incompatible with thermoplastic phases. Uniform distribution of pigment between these two phases is difficult to achieve, and mottled, uneven pigmentation results.

The dilemma is choosing between good shrink control but poor pigment with PVA or PMMA or poor shrink control but good pigmentation with no LPA.

Polystyrene, polyethylene, and caprolactone LPAs provide a range of compromises between the two extremes. Polystyrene and polyethylene additives can be molded with a wide range of close shrinkage-control levels of approximately 0.001–0.0025 inch/inch. This improves surface appearance and dimensional control over general-purpose systems, with applications for nontransportation parts because of their ability to control shrinkage. These polymers are sometimes referred to as "low-shrink additives" rather than low-profile additives.

Polycaprolactones possess better ability to control shrinkage than either polystyrene or polyethylene, and allow good pigmentation at low shrinkage levels in a narrow range of colors.

#### Lubricants

Lubricants are primarily used to improve processability by lowering melt viscosity and preventing a polymer from sticking to metal equipment surfaces. The general chemical class is alkyl acids and derivatives—esters, amides, alcohol, and metallic salts.

The PVC industry uses a high volatility lubricants, which are critical to extrusion calendaring, and injection-molding processes. Lubricants minimize friction and buildup to delay fusion to an optimum lower melt viscosity to promote flow and fusion, and reduce adhesion between melt and processing equipment. Not all lubricants perform the three functions. PVC formulations typically include a lubricant with two or more different functions. Although complete agreement is lacking, they are generally classified as external or internally functioning.